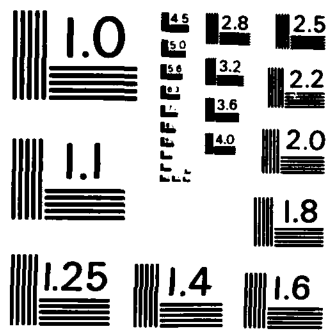
AD-A161 683 JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. B H COX 1/2

UNCLASSIFIED SEP 85 AFIT/GSM/LSY/85S-8 F/G 14/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

(2)

AF INSTITUTE OF TECHNOLOGY

JET ENGINE OPERATING AND SUPPORT COST

ESTIMATING RELATIONSHIP DEVELOPMENT

THESIS

Brenda H. Cox, GS-12

AFIT/GSM/LSY/85S-8

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSY/85S-8

JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT

THESIS

Brenda H. Cox, GS-12

AFIT/GSM/LSY/85S-8

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

Accesion For		
NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

AFIT/GSM/LSY/85S-8

JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT

THESIS

Presented to the Faculty of the School of Systems and Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

Brenda H. Cox, B.S.
GS-12

September 1985

Approved for public release; distribution unlimited

AFIT/GSM/LSY/85S-8

JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT

Brenda H. Cox, B.S.
GS-12

Approved:

Accepted:

Dean, School of Systems and Logistics

Preface

The purpose of this study was to develop a cost estimating relationship equation which predicts jet engine annual Operating and Support (O&S) costs. Users of the results of this thesis should pay attention to the content of the cost data used to develop the model. Multiple data bases were used in the effort resulting in an aggregation of non-homogeneous data. Some costs were budgetary (replenishment spares and class IV modification kit costs), other costs were expenditure (depot level organic and contractor maintenance), other costs were estimates (partial second destination transportation and contract costs on the F103-100 engine). Sources, uses, constraints, and limitations are discussed in detail for each of the costs collected.

In performing the research and writing this thesis, I have had a great deal of guidance and assistance from cost experts throughout the Air Force. I am greatly indebted to Mr. Roger Steinlage of the Cost Analysis Division, HQ Air Force Logistics Command; Ms. Eilanna Price of Requirements and Planning Office, Propulsion Systems Division, Air Force Aeronautical Logistics Center; Lieutenant Colonel Donald Owen of HQ USAF, Cost and Management Analysis Division; and Captain John Wallace of Cost and Economic Analysis Division, Accounting and Finance Center. These cost experts did me a tremendous service by reading my laborious drafts and pointing out fallacies and strengths in the study. Their questions and recommendations added immensely to the content and professionalism of the study. I am also indebted to my thesis advisor, Dr. Leroy Gill of the School of Systems and Logistics for his patience in directing me through the pitfalls of regression analysis.

A special thanks goes to my children for accepting me as the reclusive graduate student I became these last sixteen months. Their maturity, understanding and sacrifices supported me through this thesis effort.

Brenda H. Cox

Table of Contents

List of Tables

Abstract

This investigation derived a jet engine Cost Estimating Relationship (CER) model from multivariate linear regression techniques. Prior to the model's development, all known jet engine cost data bases were examined for applicability to the thesis effort. After identifying constraints and limitations in the data, stepwise regression techniques were employed to identify multivariable regression equations for analysis. The "best" equation was identified based on pre-established logic and statistical criteria. The equation selected had the following performance, physical, and usage variables: Turbine Inlet Temperature, Specific Fuel Consumption, Weight, and Annual Engine Flying Hours.

Results of the model development can be used in comparative cost analyses of present and proposed weapon systems; in cost trade-off studies to determine impact of design alternatives for new engines; in reports to Congress on the costs of operating engines; and in estimating budget requirements.

JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT

Chapter I. Introduction

General Issue

Aircraft systems incur a variety of costs during their life cycle. The major categories of life cycle costs are research and development, procurement, operating and support, and disposal (27:2).

Increasing costs to operate and support Air Force aircraft have resulted in attention being focused upon the contribution to those costs by jet engines (26:v). Headquarters United States Air Force, Directorate of Cost and Management Analysis, Cost Analysis Division (HQ USAF/ACMC) has identified the requirement for a means of predicting annual operating and support (O&S) costs of jet engines currently in the active Air Force Inventory. HQ USAF/ACMC requires predictive jet engine costs that can be used in comparative cost analyses of present and proposed weapon systems; in cost trade-off studies to determine impact of design alternatives for new engines; in reports to Congress on the costs of operating engines; and in estimating budget requirements. The purpose of this thesis is to determine a method of collecting historical jet engine cost data, and to use that historical data to develop a means that will accurately predict annual operating and support costs for those jet engines currently fielded in the Air Force active inventory (7,8,18,28,29,30).

General Approach

One of the most widely used means of estimating costs is through the use of cost estimating relationships. Cost estimating relationships are analytical tools which relate costs to explanatory variables (16:123). Frequently, these explanatory variables are physical and performance characteristics of the system for which the costs are being predicted for.

Advantages of the cost estimating relationship technique are twofold. First, the analyst can observe the effect on cost as the result of change in one or more of the explanatory variables. Second, with a cost estimating relationship, total cost can be broken down into both fixed and variable costs. Fixed costs are represented by the intercept of the cost estimating relationship equation. The coefficients preceding the explanatory variables constitute the cost contribution for each unit of the explanatory variable, e.g., variable costs.

Cost estimating relationships can range in complexity from simple rules of thumb to formal mathematical functions (16: 123). This thesis will employ multivariate linear regression as the means of predicting annual O&S costs for jet engines currently fielded in the US Air Force active inventory. Through multivariate linear regression, a cost estimating relationship equation will be developed for predicting annual jet engine O&S costs. The equation will be composed of O&S cost as the dependent variable and several jet engine performance and physical characteristics as the independent variables.

Why Existing Jet Engine O&S Cost Models Cannot Be Used

In reviewing the literature on jet engine O&S costs, there appears to be a proliferation of cost models and cost data bases. However, upon closer examination, the models and their associated data bases are usually designed for a special purpose or are designed to encompass total life cycle costs. The purpose of this thesis is to accumulate a data base from which annual jet engine O&S costs can be predicted.

Prior Effort at Engine Cost Factor Development

The need for a predictive O&S annual cost method was recognized in 1983 by HQ USAF, Directorate of Cost and Management Analysis, Cost Analysis Division (HQ USAF/ACMC) (30). HQ USAF/ACMC initiated the development of standard AF wide engine cost factors by tasking the Comptroller Support Directorate, Cost and Management Analysis Division (HQ AFAFC/CWM) with engine O&S cost factor development (18). Resulting from that original effort were an extensive data search and an approved cost element structure (CES). This cost element structure identified the categories of costs which should be included in engine O&S costs.

Specific Problem

The need for a means to predict annual jet engine O&S costs has been addressed. The main purpose of this thesis effort is to create a cost estimating relationship equation which predicts jet engine annual O&S costs.

Prior efforts either addressed the entire life cycle costs of an engine, or they addressed only a specific facet of the engine's O&S cost. This thesis will continue the initial efforts of AFAFC/CWM as directed in 1983. Using the cost element structure developed by HQ AFAFC/CWM in 1983 as a guide, this study will collect historical cost data on fielded engines, collect physical and performance data, compute historical costs, and develop multivariate linear regression cost estimating model that will accurately predict annual jet engine O&S costs.

Once developed and subsequently evaluated by Headquarters, United States Air Force, Cost and Management Analysis Division (HQ USAF/ACMC), and approved by the Air Force Cost Analysis Improvement Group (AF CAIG), the cost estimating relationship developed from this thesis will be used to compute jet engine O&S cost factors which estimate the annual cost per engine flying hour in a steady state condition. If approved, the computed factors will be published in Air Force Regulation 173-13, USAF Cost and Planning Factors.

Research Objectives

This thesis uses historical cost in order to create a cost estimating relationship that predicts annual O&S costs for jet engines currently fielded in the active Air Force inventory.

In order to accomplish the thesis purpose, the following research objectives will be investigated in the upcoming chapters.

Chapter two will examine available cost information for possible inclusion in an O&S data base. The information will be used to develop a cost estimating relationship. Existing data bases will be reviewed to identify their content, limitations, constraints, and usefulness to the thesis effort.

From investigations discussed in chapter two, chapter three will continue the thesis purpose by developing a cost collection methodology with which to collect jet engine costs from their respective data bases. Results of that cost collection will be depicted as appendices in tabular form.

Chapter four will propose a methodology for developing a predictive model. The chapter will contain analyses of independent variables that may be cost predictors.

Chapter five will use multivariate linear regression analysis to estimate a cost estimating relationship equation which predicts annual jet engine O&S costs. Analysis of the selected model's statistical merits along with conclusions and recommendations will conclude the chapter.

Chapter six is the final chapter in the thesis. It will contain thesis conclusions and suggestions for future research.

Chapter II. Data Base Search and Examination

Chapter Overview

This chapter examines the existing cost data which appears to be potentially useful for the analytical purposes of this thesis. The discussion structure of this chapter will follow the cost elements listed in Table I.

In the development and usage of cost factors and cost models, the understanding of the data base from which the factors and model were developed is critical. In understanding the composition, the user must be aware of its content, the definitions of the content, the sample size and membership, as well as the data collection methodology and analysis.

Elements of the Cost Estimating Structure

In any regression analysis effort, serious consideration must be given to the composition of the supporting data base. The composition will determine to a great extent the model's audience.

For the purpose of this thesis, the period of time for which data is to be collected has been restricted to FY 1979 through FY 1983. Examination of available data bases revealed one to have incurred changes in definition of the data collected by the data base prior to 1979 and others to have historical data only as far back as 1979. Limitations of these data bases will be addressed in the next chapter.

Existing data bases will not be checked for accuracy.

Cost elements to be included in the thesis's cost estimating relationship development effort are restricted to those already approved by HQ USAF/ACMC. The original elements were derived from the Cost Analysis Improvement Group guidance (27) by representatives from HQ USAF/ACMC, HQ AFLC Cost Analysis Division (HQ AFLC/ACMC), and HQ AFAFC/CWM during meetings in FY83. The original elements in the CES were later pared to those elements in Table I. This reduction in cost element scope resulted from discussions with HQ USAF/ACMC and HQ AFAFC/CWM (7,8,29). These are the elements which must be included if all major engine O&S costs are to be considered.

TABLE I

DETAILED COST ELEMENT STRUCTURE

Depot Maintenance
Labor
Class IV Modification Installation Labor
Direct Material
Government Furnished Material
Operations Overhead
Other Direct Cost
Base Maintenance Support
Direct Labor
Direct Material
Indirect Labor, Material, and Non-Maintenance
Contractor Maintenance
Sustaining Investment
Class IV Modification Kits
Peacetime Operating Stock Replenishment Spares
Second Destination Transportation

Cost Element Definitions

Over time, data collection policy and procedure may change. Consequently, care must be taken to precisely define cost structure elements. Cost element definitions are provided in Appendix A.

Engine Sample Size

Another consideration cost experts evaluate is the identity of the data points used to make up the data base from which the models were derived.

The Department of Defense uses an alpha-numeric code to identify aircraft and engines. For aircraft, the code represents, in descending level of detail, the mission, design, and series of the aircraft respectively. The mission codes for aircraft addressed in this thesis are A, B, C, KC, and T. They represent attack, bomber, cargo, tanker, and trainer aircraft. The next level of indenture, the design, is represented by a number code that identifies the design that the particular aircraft is. For cargo aircraft addressed in this thesis, the models are C-130, C-141, or C-5. The lowest level of aircraft weapon system identification is the series. This is represented by an alpha code. For example, the C-141 mission/design aircraft is further classified by the A and B series. Thus, depending on the degree of identification required, an aircraft weapon system can be identified by its mission, its mission/design, or its mission/design/series level of detail.

A similar hierarchy of identification is used with engine systems. The engine's alpha-numeric codes are referred to as type/model/series. For example, the F-111 mission/design aircraft are powered by the TF30 type/model jet engines. The F-111A mission/design/series aircraft is powered with the TF30-3 type/model/series engine. Identifying engine type/model/series to aircraft mission/design/series is done with the aid of the Engine Logistics Handbook (14). Engines for which a cost estimating relationship is to be developed are listed at Table II. The list includes a cross-section of various types of engines, e.g., mature engines that have been operational for many years, engines under major reconfiguration, engines under contract maintenance, and engines being converted from commercial to military usage.

Only turbo-prop, turbo-fan, and turbo-jet engines will be examined. Per HQ USAF/ACMC guidance (28), gas reciprocating engines are excluded from the thesis.

TABLE II

AIRCRAFT TO ENGINE MATCH

Aircraft	Engine	Type
A7D/K	TF41-A-1A/1B	Turbofan
A10A/B	TF34-100	Turbofan
B1A	F101-100	Augmented Turbofan
B1B	F101-102	Augmented Turbofan
B52G	J57-43WB	Turbojet
B52H	TF33-3	Turbofan
C5A	TF39-1A/C	Turbofan
KC10A	F103-100	Turbofan
C130E	T56-A-7B	Turboprop
C130H	T56-A-15	Turboprop
KC135A	J57-59W	Turbojet
KC135R	F108-100	Turbofan
KC135E	TF33-102	Turbofan
C141B	TF33-7/7A	Turbofan
F4E/G	J79-17A/C	Afterburning turbojet
F15A	F100-100	Augmented turbofan
F16A	F100-200	Augmented turbofan
F16C/D	F100-110	Augmented turbofan
F16C/D	F100-220	Augmented turbofan
F111A/E	TF30-3	Afterburning turbofan
F111D	TF30-9	Afterburning turbofan
F111F	TF30-100	Afterburning turbofan
FB111A	TF30-3/7	Afterburning turbofan
T33A	J33-A-35	Turbojet

Engine Definition

Homogeneity of the data base members is also an important consideration in the use of regression analysis. The thesis data base contains three basic types of jet engines - turboprop, turbofan, and turbojet. Functional definitions of each type of engine are identified at Appendix B.

The traditional cost model development process entails comparing performance and physical characteristics of the sample members to a cost data base through regression and correlation analyses. This thesis differs from traditional model development in that it consolidates cost elements from a variety of historical data bases instead of a single homogeneous data base. For each cost element there may be a variety of data bases from which historical costs could be extracted. The content of the data bases for each element differ because of differences in the purposes or the definitions of the data bases.

There are two philosophies on collecting costs for analyses. The first philosophy is termed "the cost of doing business". With this view point, costs are collected as they are obligated. These costs are defined as obligations. Cost models and factors based on obligations are developed for budgetary and programming purposes. One of the possible uses of the results of this thesis is to develop predictions to be used in estimating budget requirements. For that intention, obligation costs will be used wherever possible.

The second philosophy is "the cost of operations". With this view point, costs are collected as the resources are used. These types of costs are labeled expenditures. The major difference between these two types of cost is that obligations are the dollar amount of purchased resources recorded on a transaction that will require future payment of money (37:482). Whereas, expenditures are the dollar amount of the check/cash issued for the obligated purchase (37:275). Obligations are resources planned for future consumption. Expenditures are resources being consumed.

Depot Maintenance Data Source

The most accepted data source for depot maintenance cost factors is the HO36C, Weapon System Cost Retrieval System (WSCRS). It is used by cost analysts at HQ AFLC, HQ Systems Command, HQ AFAFC/CWM, and HQ USAF/ACM. WSCRS is a HQ AFLC automated data base designed to support cost analysis projects. It provides one consistent source of historic cost information on aircraft depot level maintenance. WSCRS retains historical cost for the last ten years and will continue to accumulate depot level maintenance costs for each succeeding year. Office of Primary Responsibility for WSCRS is HQ AFLC/ACMCI (13,38).

WSCRS is used by a variety of analysts in predicting depot maintenance costs for current and future aircraft systems (38).

WSCRS cost data, as it pertains to jet engines, contains organic manhour labor costs, material costs, contractor costs, interservice charges (work performed by another DoD department and charged to the Air Force), government furnished equipment costs, and overhead costs. These costs are defined as expenditures in that the cost data represents the value of resources as those resources are expended. The means of sorting the costs to specific aircraft and engines is through the use of mission/design/

series and type/model/series codes.

The expenditures currently collected in WSCRS are from 1975 through 1984. These historical costs can be extracted via an automated retrieval process. The actual costs that were recorded can be inflated/deflated to any year's dollars that the requester desires (38).

WSCRS is limited by the requirement to allocate common costs among a family of engines. WSCRS will track actual cost to the engine type/model/series level. It will not track costs to the type/model/series by mission/design/series. Instead, it allocates type/model/series cost to the mission/design/series by using engine flying hours to prorate the costs. For example, the TF30-3 type/model/series engine powers the F-111A, FB-111A, F-111E, and EF-111A mission/design/series aircraft. In order to allocate the costs of the TF30-3 to the various aircraft, WSCRS will take the total TF30-3 depot costs and allocate those costs among the applicable F-111 aircraft according to the number of engine flying hours attributed to the respective aircraft series. The aircraft series having the largest number of flying hours will automatically incur the largest amount of TF30-3 costs.

WSCRS will track engine component cost directly to type/model/series, if the cost is to a unique component that belongs to a specific type/model/series. Common engine parts are allocated among the applicable type/model/series members. During engine design, engineers and logisticians try to retain as much commonality among parts as possible. For example, the TF-30 family of engines has TF-3, TF-7, TF-9, and TF-100 series. WSCRS will place actual costs of unique TF-30-3 parts to the TF30-30-3 engine. Any parts that are common to the TF-30 family, will be allocated to the family members based on engine flying hours, regardless of which series actually incurred the cost (38).

These allocations of cost among type/model families and to mission/design/series aircraft make WSCRS costs a mix of actual and allocated costs. This limitation is due to the requirements and capabilities of existing automated data processing systems and to existing administrative maintenance procedures (38). These systems do not have the capability to track costs to the end item (specific engine system).

WSCRS tracks costs only on those weapon systems that HQ AFLC has responsibility for maintaining. Those engines under Contractor Logistics Support maintenance, under major reconfiguration, or still in development are not tracked by WSCRS.

WSCRS is a depot maintenance data base that collects historical jet engine costs. It is widely accepted and used throughout the Air Force. It has been institutionalized as the common source for aircraft depot maintenance cost data.

Base Maintenance Data Source

Maintenance Collection System. Traditionally, base maintenance costs have been extracted from the Maintenance Cost System (MCS). The MCS is a repository data base for a variety of base data from a number of automated data sources. The MCS provides information on the cost of civilian and military staff-hours, the cost of productive direct and indirect hours, and the cost to maintain aircraft and engines. Feeder systems to the MCS are the Maintenance Data Collection System (MDCS), the Exception Time Accounting System, The Standard Base Supply System, the Base Level General Accounting and Finance System, the Civilian Payroll System, the Aerospace Vehicle Inventory Status Reporting System (AVISURS), and Major Commands (MAJCOMS) unique data systems. The costs collected by the MCS are expenditures, meaning that they cover the use and consumption of resources rather than the obligation or commitment of funds (17:56). "The MDCS, one of the key inputs to the MCS, is the primary source of base-level maintenance data. The data processed by the system consists primarily of maintenance staff-hour expenditures and technical data involving maintenance tasks that are accomplished. Data on maintenance performed is documented manually on AF Form 349, collected, keypunched, and processed at the base level for report output and computer storage" (17:3).

The MCS is the major source of base-level maintenance cost data. "It accumulates staff-hour data from the MDCS to support the Command Aerospace Maintenance Manpower Information System and cost data for aircraft maintenance organizations" (17:16). It tracks costs by Work Unit Code (WUC) to the respective mission/design/series aircraft. The costs are categorized as Military Labor, Civilian Labor, Material (funded), Material (unfunded), Contract, Indirect, Overhead, and Total (1).

Since its development, the MCS has had significant accuracy problems. The source of these accuracy problems has been identified by the General Accounting Office to inaccuracies in the feeder system, MDCS (17:11). The GAO reported that "for more than 20 years, the Air Force has collected, processed, and disseminated inaccurate and incomplete maintenance information through its MDCS" (17:8). The GAO report cited multiple examples of MDCS erroneous data collection. A contractor audit in 1978 found that "the number of maintenance actions were under reported by a factor of two, the number of direct labor hours sampled by the contractor were over reported by a factor of 2, and that more than half of the tasks they observed could not be matched with any reported account of work performed. The contractor concluded that the inaccurate data had several ramifications for maintenance and cost analysis in the Air Force" (17:12). "An April 1982 MCS mismatch report showed that Travis AFB had 436 part removals with no matching installation data submitted to the MDC system" (17:13).

As a result of the inaccuracies in the MDCS feeder report to the MCS, analysts at HQ USAF/ACMC strongly recommended against using the MCS system as the source of base level maintenance (28).

VAMOSC/CSCS. There is a data base that has been designed to collect all costs associated with the aircraft's major component parts. The data base is the Component Support Cost System portion of the Visibility and Management of Operating and Support Costs (VAMOSC) data base.

CSCS attempts to collect O&S costs on base, depot, overhead, spares, modification and time compliance technical order kits, and transportation expenses of aircraft and their major subsystems and components. It then depicts those costs at the work unit code (WUC) level, for 72 aircraft, by fiscal year in which the costs were incurred. Like WSCRS, the costs collected by CSCS are expenditure costs.

The objectives of CSCS are to:

- Identify aircraft subsystem component O&S costs.

- Display information in standard formats.

- Provide demand-type products for specific objectives.

- Improve the Air Force life cycle cost capability.

- Maintain the data base for 10 years.

- Provide national stock number (NSN)/WUC cross-reference capability.

The overall intent of CSCS is to provide a standardized O&S cost data base from which analyses on aircraft weapon systems can be performed (19).

There are three drawbacks with the VAMOSC model:

1. CSCS base level manhour costs are obtained from the D056 which is the extension of the error plagued MDCS (19).

2. CSCS has only four quarters of historical engine data collected (19). This is an insufficient amount of data for a factor development analysis.

3. CSCS tracks costs by Work Unit Code and not by type/model/series.

The lack of historical cost data precludes the use of CSCS at this time.

Other Base-Level Maintenance Data Systems. A number of other information systems are used to satisfy managers' needs for information about maintenance activities. Some of the operational information systems that track base level costs include the Maintenance Management Information and Control System (MMICS), and the Product Performance System (D056) (17:5).

MMICS is the standard automated Air Force maintenance information system at the base level. It is an online computerized system used to track and control maintenance resources at more than 100 Air Force bases worldwide. MMICS is a managerial system, providing schedules, inventory levels, and personnel status to base level maintenance managers (23). MMICS does not track engine costs by type/model/series.

The Product Performance System (D056) is an extension of the MDCS in that it summarizes the MDCS data (17:14-15). "The D056 processes MDCS data to provide weapon system and item managers with reliability and maintainability information. It provides measures or indicators of weapons system performance such as the average number of operation hours between maintenance actions and maintenance staffing requirements by weapon system" (17:15). In that the D056 summarizes MDCS data, it also becomes subject to criticism due to the inaccuracies in the MDCS.

Considering that MCS is unreliable, that CSCS has limited historical cost data, and that other base level maintenance systems are managerial and not cost in nature, the analyst has no existing base level history that is approved by HQ USAF/ACMC from which to develop engine cost factors.

The recourse is to survey bases that service only one type of mission/design/series aircraft and one type/model/series engine. The survey would request the base provide historical manpower and material costs for the propulsion shop. This effort duplicates the effort of MCS. The effort is also beyond the scope of this thesis. In addition, bases are required to maintain historical records for only two years. Two years of cost data is insufficient for a reliable cost estimating relationship effort.

With the exception of MCS and CSCS, the above base maintenance data bases were designed to aid managers in the control, coordination, evaluation, and planning of resources. They were not designed to collect costs.

Of the available base maintenance data bases, one is considered unreliable (MCS), another has insufficient historical cost (CSCS), and two others do not collect costs at the type/model/series level (MMICS and D056). Investigation revealed no other existing data sources from which to develop base level cost factors. Consequently, base maintenance cost factors cannot be incorporated into the thesis effort.

Deletion of Base Maintenance costs from the Cost Element Structure will void any attempt at developing a "total O&S cost model". At this juncture, only a partial cost estimating relationship model based on partial O&S costs can be developed.

Contractor Maintenance Data Source

In addition to the amount of maintenance performed at the depot and base levels, there is a considerable amount of maintenance performed under contracts with commercial industries. This contract maintenance contributes to the O&S cost of the engine and should be included in a jet engine O&S cost model. There are five types of contractor maintenance costs. The types and definitions follow:

1. Depot Purchased Equipment Maintenance (DPEM) is requested through the system manager to support less-than-major systems, equipment, and modifications. It is planned and used when certain organic support resources are not available.

2. Contractor Logistics Support (CLS) is a permanent (entire life) logistics support alternative for a weapon system or subsystem. It is a method of providing all or portions or organizational, intermediate, or depot maintenance required to support a weapon system, weapon subsystem, or item of equipment. Contractor logistics support is normally used to support short operational-life systems, or small inventories of commercial, off-the-shelf aircraft or equipment when establishment of AFLC organic life cycle logistics support is not planned for various reasons. Spares and repair parts are obtained off-the shelf and are not normally provisioned and stocklisted by the Air Force.

Under contractor logistics support it is common for the contractor to provide all elements of support.

3. Interim Contractor Support (ICS) is a temporary, cost effective logistics support alternative for new USAF weapons systems, equipment or class V modifications. It allows the Air Force to defer all or part of its investment in support resources until risk has been reduced.

4. Contractor Support/Program Assisted (CS/PA) is an unplanned use of contractor support for unforeseen emergency logistics support requirements. The causes for Contractor support/program assisted include schedule slippage or acceleration, logistics support development funding shortage, shortfall in availability of logistics support resources, or inadequate program planning.

5. Interservice is maintenance, either recurring or nonrecurring, performed by the organic capability of one military service in support of another military service.

Sources for contractor costs vary according to the type of contract cost. As discussed in the search for depot maintenance cost data, WSCRS contains historical cost for manhour, material, and overhead expense elements. Included within those broad categories of cost are contract and interservice costs. Of the five contract types defined above, WSCRS contains Depot Purchased Equipment Maintenance, Contractor Support/Program Assisted, and interservice costs. WSCRS does not contain Contractor Logistics Support or Interim Contractor Support costs.

WSCRS is a widely recognized source for depot maintenance on those aircraft currently fielded, both contract and organic. Because of its acceptability, no further search for alternate data bases was made. WSCRS is also restricted to those engines under HQ AFLC maintenance responsibility. Those engines under the responsiblity of HQ Systems Command will not be reported on by WSCRS.

Of the engines in the study sample, only the KC10A engine (F103-100) is maintained under Contractor Logistics Support/Interim Contractor Support contracts. Cost data for the F103-100 engine will have to come from funds managers in the KC10A Program Office.

The F103-100 engine powers two aircraft, the KC10A and the E4. Both of these aircraft are under contractor logistics support contracts. The KC10A aircraft and engine are incorporated into one contract, precluding separating engine from aircraft costs. The E4 aircraft and engine are under two contracts, allowing identification of engine from aircraft costs. However, the E4 was not included in the thesis sample size. As a result, the KC10A Program Office is the only known source for the F103-100 engine as it relates to the KC10A cost data. Conversations with the KC10A program managers indicate that contractor proposals would be an appropriate source for identifying F103-100 engine costs as they pertain to the KC10A.

WSCRS, a widely accepted historical cost data base, will be used for determining most engine contract/inter-service costs. The exceptions, the F103-100 and engines under HQ Systems Command responsiblity, requires estimation from contractor proposals or other sources.

Sustaining Investment Data Source

The second major category of cost identified in Table I is sustaining investment. In accordance with the Cost Analysis Improvement Group definitions, sustaining investment includes the following categories of cost: replenishment spares, replacement support equipment, modification kits, and other recurring investment (27:2). Due to the availability of historical data bases, Sustaining investment is restricted to those costs associated with replenishing spare parts and with providing class IV modification kits on engines for safety, maintainability, and reliability purposes.

Replenishment spares are the first element of sustaining investment costs. Spare parts cost data can be obtained from either WSCRS or from a HQ AFLC, Investment Material Division, Replenishment Spares Branch (MMMIR) developed data base.

The costs collected by WSCRS follow the cost of operations philosophy. The costs represent expenditures. The WSCRS retrieval contains a line for "condemnations". Condemnations are parts for which the base or depot has decided that it cannot repaired and subsequently condemns it. Condemnations also include those parts removed by the depot during depot overhaul which cannot be repaired and are subsequently condemned (38).

HQ AFLC/MMMIR has developed a historical data base which captures the procurement of Peace Time Operating Stocks, War Readiness Spares Kits, and Base Level Self Sufficiency Spares. These costs represent the obligation of funds as the parts are ordered by the item managers at the five Air Logistics Centers (ALC's) (40). It represents the cost of doing business philosophy.

Included in the data base are spares costs destined for Foreign Military Sales. Inclusion of Foreign Military Sales cost will overstate the cost of jet engines associated with the sale. However, conversations with HQ USAF/ACMC personnel indicate that only the J85 engine which powers the F-5 aircraft has significant amounts of Foreign Military Sales dollars invested in replenishment spares. Since the engine members selected for this thesis data base exclude the J85, a model derived from the MMMIR data base should not be severely over valued.

The MMMIR data base is derived in the following manner:

Source documents for the MMMIR data base are Budget Documents, Status of Funds Reports (H058), and HQ AFLC funding guidance. Budget documents include budget submissions (brochure), Budget Estimation Submission (BES), Program Operating Memorandum, and President's Budget (40).

Inventory Management Specialists (also called Program Managers and Funds Managers) at the Air Logistics Center's Investment Material Offices coordinate with Item Managers, Equipment Specialists, Requirements Control Officers, and individuals from the engine area. Together with their technical expertise and the amount of money the weapons system is budgeted for, a technical estimate is developed that approximates the replenishment spares obligated for each engine weapon system (40).

The MMMIR data base is a HQ AFLC product. Consequently, engines not under the maintenance responsibility of HQ AFLC were not reported on by the MMMIR data base.

Modification kit costs represent the second component of Sustaining Investment costs. Modification kits are the physical result of a design change after the engine has been fielded. Either the contractor or the government initiates a design change which causes the engine to be modified. There are various types of changes. They include safety, security, performance enhancement, and reliability changes. The modification can occur at depot during overhaul or at base level via Time Compliance Technical Order (TCTO).

The type of modification kit that pertains to O&S cost factor development is the class IV modification kit. This modification is initiated to enhance the maintainability, safety, and reliability of the engine. It does not change the form, fit or function of the engine nor does it significantly enhance its performance.

As with the replenishment spares, there are two philosophies of collecting costs. The "cost of operations" can be found in WSCRS. The "cost of doing business" can be obtained from the Air Logistic Center funds managers at Oklahoma City and San Antonio depots. As with the MMMIR data base, modification kit costs are available only for those engines under HQ AFLC maintenance responsibility

There are two sources for both replenishment spares and class IV modification kit costs. In a 21 February 1985 staff visit by HQ USAF/ACMC and HQ AFAFC/CWM to HQ AFLC/ACMCI, the question of which philosophy to pursue was answered based on the need for predictive budgetary costs. The cost of doing business for replenishment spares and modification kits will be the direction for engine O&S cost factors (29). Therefore, replenishment spares costs will come from the MMMIR data base and modification kit costs will come from the ALC funds managers at Oklahoma City and San Antonio.

Use of the MMMIR replenishment spares data base and the modification kit inputs from funds managers causes non-homogeneity of data types in the thesis' effort to develop a predictive cost model. WSCRS depot maintenance cost data reflects expenditures. MMMIR and fund manager cost data represents obligations.

The MMMIR replenishment spares data base collects engine spares data at the type/model level. It does not depict costs down to the type/model/series level. The data provided by the Air Logistic Center funds managers is also collected at the type/model level, not down to the type/model/series level. The one exception is the TF30 engine. The funds manager at Oklahoma City ALC had the data grouped with the TF30-3,-7,-9 engines together and the TF30-100 separate.

Both the replenishment spares and the modification kit cost data bases fall under HQ AFLC responsibility. Consequently, costs for engines under HQ Systems Command will have to come from other sources.

Second Destination Transportation Data Source

The third major cost category to be included in the thesis O&S model development is Second Destination Transportation (SDT). SDT costs are those costs incurred when engines, components, parts, kits, etc., are transported between the bases and the depots. Historically, SDT costs have been computed by taking the weight of the engines and engine subelements returned to depot for repair from the base (Not Repairable This Station) and multiplying that weight by the standard cost factors in AFLCP 173-10, HQ AFLC Cost and Planning Factors, and then multiplying that by a factor of 2 to allow for round trip costs (15).

The Component Support Cost System, uses an algorithm of this nature and attempts to collect transportation costs on engines, kits, and consumed replenishment spares. Due to systems difficulty CSCS could not produce these costs (19).

According to HQ AFLC Directorate of Programs/ Resources, Budget Requirements Division experts (35) and HQ USAF/ACM, there are no existing data bases that depict transportation costs on aircraft weapon systems. For the purpose of this thesis effort, SDT costs are developed by taking the number of whole engines and T56 and F100 modules overhauled per year (production counts), multiplying the result by the engine weight, multiplying that result by 2 (round trip cost), and multiplying the result by the FY CONUS (Continental United States) shipping rate inflated to FY 85 dollars.

To employ this recommended method of determining SDT costs, three data sources must be utilized. The source for the number of engines and modules overhauled per year (production counts), is from data extracted by HQ AFLC/ ACMCI from the LOG-MA(Q) 7312 report (4). The source for engine weight is from Transportation Plan 71-1 on Jet Aircraft Engines (39) provided by the Traffic Branch, Oklahoma City ALC. The source for CONUS shipping rates is from AFLCP 173-10 (3), inflated by USAF weighted inflation indices (12).

The proposed methodology for estimating SDT restricts the cost of SDT to only that cost associated with transporting whole engines and the T56 and F100 modules. It ignores the contribution resulting from the transportation of engine repairable items (repairables). This limitation requires the SDT contribution to an engine cost factor to be redefined as Partial Second Destination Transportation.

The LOG-MA(Q) 7312 report depicts production counts down to the type/model/series level for whole engines and modules. However, considering the small dollar impact partial SDT has on an engine O&S cost per engine flying hour factor in proportion with other cost elements, the SDT costs will be computed at the type/model level. Summary production counts at the type/model level are readily available in the HQ AFLC Depot Maintenance Annual Reports (2).

There is no existing SDT cost data base for jet engines. Therefore, the SDT cost must be estimated. The proposed methodology for estimating SDT costs relies upon whole engine and module production counts. It does not take into consideration shipment of repairable items. This methodology reduces the contribution of SDT to an engine cost model. Consequently, the definition of SDT must be changed to partial SDT.

Data Base Search and Examination Conclusions

This chapter has examined the costs which can be included in an O&S data base for the purpose of developing a predictive cost estimating relationship model.

Table III summarizes the cost elements used in this thesis research and their sources.

TABLE III

DATA BASE SOURCE SUMMARY

Element	Source
Depot Maintenance	WSCRS
Contractor Maintenance	
DPEM, CS/PA, Interservice	WSCRS
Contractor Logistics Support	KC10A Program Office
Replenishment Spares	MMMIR Requirements/ Funding History
Modification Kits	ALC Funds Managers
Second Destination Transportation	Computed from Weights, Rates, and Production Counts

Use of the selected sources results in a problem of non-homogeneity of data. Four of the sources collect costs as they are expensed, creating expenditure data. The other two sources collect costs as they are obligated, creating obligation data. The following Table IV summarizes the cost elements and their respective type of costs.

TABLE IV

DATA TYPE SUMMARY

Element	Source
Depot Maintenance	Expenditure
Contractor Maintenance	
DPEM, CLS/PA, Interservice	Expenditure
Contractor Logistics Support	Expenditure
Replenishment Spares	Obligation
Modification Kits	Obligation
Partial Second Destination Transportation	Expenditure

Chapter III will explain how costs are extracted from each of the selected cost sources. Chapter IV will discuss how the extracted costs are used to develop a cost estimating relationship model.

Chapter III. Cost Collection Methodology

Chapter Overview

The engines used in the thesis research are maintained by different organizations. The older fielded engines are under HQ AFLC maintenance responsibility and have adequate historical cost records. The contractor logistics support engine, the F103-100, does not have a historical cost data base as it pertains to the KC10A aircraft. The same limitation is true of the newer jet engines still under Systems Command maintenance responsibility. Both the contractor maintained engine and the Systems Command maintained engines require different methodologies for collecting and predicting costs. This chapter will discuss the three different methodologies used to obtain costs for the members in the thesis sample size.

HQ AFLC Maintained Jet Engines Methodology

The general methodology for cost collection entailed locating historical data for depot, sustaining investment, and second destination transportation, from pre-established data bases; separating the costs by fiscal year (FY) to the appropriate engine type/model; inflating the cost to FY85 constant year dollars; and rounding the costs to the nearest thousand dollars. Specific methodology for each cost element source varies with the assumptions and limitations imposed by the data sources.

__Depot Maintenance Cost Collection.__ Depot maintenance costs were extracted by obtaining a special WSCRS retrieval from HQ AFLC/ACMCI, Depot Maintenance Weapon System Cost Data (RCS: HAF-ACM-(A&AR) 8202) Cost Summary in FY85 dollars, that identifies peculiar or allocates common depot maintenance expenditures by type/model/series by fiscal year (9).

Cost elements extracted from the retrieval were:

Direct Labor (military/civilian/other)

Direct Material

Government Furnished Expense Material

Government Funded Services

Operations Overhead

Other Direct Materials, Labor, and Non-maintenance

Contractor and Interservice

The elements were summed at the type/model level to get a fiscal year depot maintenance cost for each year. The extraction provided five years (FY79 - FY83) of depot maintenance cost. Manual computational errors and missing data (J57-43 and TF41 engines) necessitated some recomputations and substitution of some FY83 WSCRS cost data with FY82 WSCRS costs data (inflated to FY85 dollars). FY 83 data on the J57-43 engine was not available. The FY 83 cost and engine flying hours for the J57-43 were omitted from the data collection process. Extracted depot maintenance costs are at Appendix C.

Intuitively, O&S costs of jet engines would be expected to be greater the more frequently the engine is used. Comparing O&S costs of a less utilized engine to a higher utilized engine gives a biased perspective. To obtain a relative perspective of how costly the engines are when compared to each other, each type/model depot maintenance cost was divided by the appropriate number of engine flying hours to obtain a depot maintenance cost per engine flying hour. Those historical cost factors per engine flying hour are located at Appendix D.

The engine flying hours used to obtain a per engine flying hour factor were extracted from the WSCRS data base. The engine flying hours used to obtain the depot maintenance cost per engine flying hour factor and all subsequent per engine flying hour factors are itemized in Appendix E.

Sustaining Investment Cost Collection. As discussed in Chapter II, sustaining investment has two major components - replenishment spares and class IV modification kit costs. The data sources for the two components came from separate sources which required separate cost collection methodologies.

Replenishment Spares. HQ AFLC/MMMIR has a Requirements/Funding History report that depicts the total funding for replenishment spares by type/model for those engines under HQ AFLC maintenance responsibility (25). This cost report includes Peace Time Operating Stocks (POS), War Readiness Spares Kit (WRSK), Base Level Self Sufficiency Spares (BLSS), and Other War Readiness Material (OWRM). To be compatible with aircraft O&S cost factors (28), only the Peace Time Operating Stocks (POS) portion of the total replenishment spares cost was extracted from the report. These costs are for replenishment buys only. They do not include initial spares or modification kits costs. Since the costs on the report are in "then year dollars", i.e., the year in which the cost occurred, each POS funding amount for each fiscal year and each type/model had to be inflated to 1985 year dollars. This allows for a true representation of growth in cost. The inflation indices used were those documented on table 5-3 of AFR 173-10 (12). For three of the engines, MMMIR had zero entries for some of the fiscal years. Cause for the zero entries was attributed to two possibilities. The first was that the source documentation to obtain a fisal year cost value was not available. The second reason was that replenishment spare parts were not purchased in those years. The data base manager felt that the T56 and J33 data had zero entries due to lack of source documents. It is possible that replenishment spares for the J33 engine were not purchased in FY83.

Lack of accurate cost data could understate the annual costs for these three engines. In addition to potential understatement the inclusion of Foreign Military Sales cost data in the MMMIR data base is most likely to overstate the annual historical costs for all the engines.

The F100 (-100, -200) engine POS replenishment spares data was not recorded in the MMMIR data base. Instead, it was provided by the San Antonio Requirements Analyst at the San Antonio ALC (20).

Extracted POS replenishment spares cost data is at Appendix F.

Modification Kit Costs. The second component of sustaining investment, class IV modification kit costs, came from a different data base than did the first component, replenishment spares. Modification kit costs per type/model per fiscal year were extracted from information provided by the funds managers at the San Antonio and Oklahoma City Air Logistic Centers (5,22). Since the costs were expressed in then year dollars, they were inflated to FY 85 dollars using Table 5-3 in AFR 173-13 (12).

Extracted class IV modification kit costs are shown at Appendix G. Zero entries indicate that kit materials were not purchased during the fiscal year.

Summation of Replenishment Spares and Modification Kit Costs. The annual costs per engine for replenishment spares and modification kits were summed to obtain an annual sustaining investment cost per engine. Appendix H depicts the annual sustaining investment cost per engine.

To obtain a comparative cost factor for each engine, sustaining investment costs per engine flying hour were computed by dividing the annual sustaining investment cost per engine by the number of annual engine flying hours. Those comparative factors are given at Appendix I.

Second Destination Transportation Cost Collection. Second Destination Transportation costs for each type/model level of engine were obtained by multiplying the number of engines overhauled per year (2) by the gross packaged engine weight (39). The resulting value was multiplied by two in order to ensure round trip costs. Next, the resulting value was then multiplied by the then year CONUS shipping rate (3) inflated to FY 85 dollars (12).

Engines can be shipped in containers or on trailers, shipped by truck or by plane, shipped to CONUS locations or overseas locations. For the purpose of this thesis, the engine weight as packaged in a container was used (39). When container weights were not provided, then trailer weights were used (39). In some instances, multiple trailers or containers with different weights could be used on the same engine. When multiple packaging weights for the same engine were available, an average weight was computed. In the event the engine was not listed, a factor of 1.52 was multiplied by the listed engine weight (14) in order to obtain an approximate shipping weight. This 1.52 factor was derived by comparing the engine weight (14) to the adjusted gross weight when packaged (39). The raw average difference between the two weights ranged from a factor of 1.043 to a factor of 2.487. The average difference for the fielded engines studied in in this thesis was 1.52. In the transportation plan, only the packaged weights of whole engines were listed. Several of the engines in the study sample are modular in design. That is the whole engine is designed into easily separated and repaired parts (modules) that can be removed and be replaced in lieu of the whole engine being removed and repaired. For example, the F100 engine has six modules. They are the engine core, the inlet fan, the fan drive, the augmenter, the gearbox, and the high pressure turbine. An attempt was made to locate module weights for the F100 and T56 engines but none were found. For the F100 and T56 engines that had modules overhauled, the module weight was derived by dividing the engine weight by the number of modules in the engine. This weight per module was then multiplied by the 1.52 factor to obtain an estimated packaged weight per module.

CONUS surface government bill of lading cost per pound factors were extracted from historical issues of AFLCP 173-10 (3). Fiscal year 1979 cost per pound was not avail- able. For a FY79 estimate, the FY80 value was used without adjustment. Each cost per pound estimate was inflated to FY85 dollars using OSD inflation rates for O&S 3400 non-POL and non-Pay category (12).

Appendix J contains the computed annual partial Second Destination Transportation costs for those engines under HQ AFLC maintenance responsibility. Appendix K depicts the computed annual partial Second Destination Transportation costs per engine flying hour. In the event the cost per engine flying hour was less than one dollar, the amount was entered as zero.

Cost Collection Methodology for Engines Under HQ Systems Command Maintenance Responsibility

Of the sample engines under study in this thesis, the six in Table V are not the maintenance responsibility of HQ AFLC. Consequently, alternate means of data collection were used to obtain cost per engine flying hour estimates.

TABLE V

JET ENGINES NOT MAINTAINED BY HQ AFLC

Engine	Aircraft
F100-110	F15/F16 (re-engine)
F100-220	F15/F16 (re-engine)
F108	KC135Q
F101-100	B1A
F101-102	B1B
F103-100	KC10A

Base Operating and Support Cost Model. Estimates for all but the F103-100 were obtained from the Requirements and Planning Office, Propulsion System Division, Air Force Aeronautical Logistics Center (HQ AFLC/YZLR). YZLR used the Base Operating and Support Cost Model (BOSC) to derive the cost per engine flying hour estimates (33,31).

The BOSC Model takes engineering estimates for the inputs in Table VI and outputs projected O&S costs over a given period of production years.

TABLE VI

BOSC MODEL INPUTS

Total PAA
Shop Utilization Rate
Organizational Maintenance Hours
Number of Production Years
Number of Steady State Years
Constant Year Dollars
Inflation Factors
Unit Price (of an average buy)
Whole Spare Engines Quantity

Outside of the model, YZLR will compute second destination transportation and replacement support equipment. These factors will be added to the model as inputs. Outputs of the model are depot (organic and contract) maintenance, base maintenance, and replenishment spares. Maintenance includes both material and labor. The spares cost include condemnations only.

For the cost per engine flying hour estimates generated from the BOSC model, two assumptions were made: (1) the engine is in a steady state configuration and (2) the engine is mature. The costs per engine flying hour in Table VII were generated from BOSC using YZLR's latest engineering input.

TABLE VII

BOSC MODEL ESTIMATES

Engine	Estimate
F100-110	$240 - $315 / EFHR
F100-220	$240 - $315 / EFHR
F108	$52.50 / EFHR
F101-100	$280 / EFHR
F101-102	$280 / EFHR

Content of the BOSC estimates include depot maintenance, base maintenance, and replenishment spares. High to low ranges were provided for the F100-100 and F100-220 engines. Reason for the range was the sensitivity of costs in the source selection process.

The estimates provided by the BOSC model differ in content from the factors computed for HQ AFLC maintained engines. The difference is that these BOSC estimates include base maintenance but exclude second destination transportation and class IV modification kits.

DD Form 633, Contractor Proposal

The last engine in the study sample, the F103-100, is maintained through contractor logistics support (CLS). Examination of WSCRS data revealed costs collected for the E4 aircraft, also powered by the F103-100, but no cost data for the KC10A.

In contacting the Airlift and Training System Program Office budget office (10) the following methodology was devised using contractor proposals itemized on a DD Form 633 in order to approximate contractor cost:

> Flying hour program X base year cost rate
> X program peculiar inflation rates to get then
> year cost / OSD inflation index = FY 85
> dollar costs.

The contractor estimated cost was then divided by engine flying hours (aircraft hours X three engines) to obtain a cost per engine flying hour factor for comparing to the other per engine flying hour estimates.

From the above methodology, the estimates in Table VIII were derived.

TABLE VIII

F103-100 ENGINE ESTIMATED COSTS

FY	FlyHrs	Base Year Cost Rate	Inflation Rate	OSD Inflation	Cost/EFHR Estimate
81	1127.2	102.14	1.3480	.8651	$53
82	5649.6	102.14	1.5255	.9327	$56
83	11700.6	102.14	1.6757	.9719	$59
84	17985.0	102.14	1.7652	1.0298	$58

The estimates in Table VIII include costs for engine overhaul, intermediate repair, and replenishment spares. These estimates contain yet another different composition than did the HQ AFLC and HQ Systems Command maintained engines. The estimates exclude class IV modification kits and second destination transportation.

Chapter Summary

Three different approaches were employed to derive annual costs per engine and per engine flying hour estimates. The approaches depended upon whether the engines were maintained by HQ AFLC, HQ Systems Command, or by contractor logistics support.

Each approach estimated costs differently, varying with the cost source. The costs for HQ AFLC engines were obtained from non-homogeneous historical data bases. Some of the cost elements were expenditure data and others were obligation data. The cost for the contractor logistics support engine were obtained by estimation using inputs from the contractor's original proposal (DD Form 633). Estimates for the HQ Systems Command maintained engines were derived from the BOSC cost estimating model.

Because each of the different approaches employed different cost elements, care is advised in the use of these factors for comparison purposes when the engine factors are derived from separate sources.

The purpose of this thesis is to develop a means of predicting costs for jet engines currently fielded and in the active Air Force Inventory. Since those engines not under HQ AFLC maintenance responsibility do not have a historical cost data base with which to compare physical and performance characteristics, they will be deleted from the development of a cost estimating relationship model.

O&S cost per engine flying hour (as defined by the three different approaches and as restricted to available costs) are depicted in Appendices L through N.

This chapter accomplished the research objective of developing a cost collection methodology with which to collect jet engine costs from their respective data bases. The next chapter will discuss the process followed in the development of a cost estimating relationship model. The process will use these collected costs as the model's independent variable and will examine multiple physical and performance characteristics in search of potential dependent variables.

Chapter IV. Cost Estimating Model Development Methodology

Chapter Overview

The purpose of this chapter is to use historical cost data in order to develop a cost estimating model that will accurately predict O&S cost for those engines currently fielded in the USAF active inventory. Once reviewed by HQ USAF/ACMC and approved by the Air Force Cost Analysis Improvement Group, engine O&S cost factors that depict the annual cost per engine flying hour in a steady state condition will be published in Air Force Regulation 173-13, USAF Cost and Planning Factors.

In Chapter III, Cost Collection Methodology, the discussion of the various sources and uses of cost data re-identified a major difficulty in developing a predictive O&S cost model. That difficulty is the lack of "disaggregated, homogeneous, longitudinal data associated with specific engine types" that was identified by Rand Corporation researchers in March 1977 (26:1). This lack of suitable historical cost data reduced the thesis' scope from development of a total O&S cost model to a model that addresses only depot maintenance, sustaining investment, and partial second destination transportation.

This chapter follows closely the steps the Rand Corporation researchers used in their October 1982 study on the <u>Development and Production Cost Estimating Relationships for Aircraft Turbine Engines</u> (6). Although, the Rand study examined both development and production phases of engine life cycle costs, this thesis addresses only the operating and support phase of jet engine life cycle costs.

This chapter will explain the methodology used to develop cost estimating relationships. Historical cost data collected on those engines under HQ AFLC maintenance responsibility along with physical and performance characteristics were used to develop various cost estimating relationships.

A cost estimating relationships was selected as the best means of predicting jet engine O&S costs. With a cost estimating relationship the estimated cost is more atuned to the changes in the independent variables. Thus, as the engine's physical and performance characteristics change, so can the cost estimate.

Selection of the Independent Variables

Following the logic used by the Rand researchers, three criteria for selection of independent variables were set forth (6:12). The first criteria was that the variable had to be logically related to O&S costs. The second criteria was the variable had to be known with a fair degree of accuracy. The third criteria was that the variable had to be readily obtainable.

In examining various physical and performance characteristics of jet engines, it was hypothesized that O&S costs were a function of the following:

1. The size of the engine. The size of the engine is an indication of the number of parts and complexity of the engine. The greater number of parts and the more complex they are, a higher cost to maintain the engine is expected. The variable indicative of size that was most readily available was engine weight.

2. The technology and performance incorporated into the engine. Technology may expand the mean time between failure and it may decrease the mean time to repair. These two measures of maintainability would tend to decrease O&S cost. However, increased technology also suggests more complex and costly parts, more complex testing equipment, and more highly skilled laborers to maintain the engines. Variables indicative of technology and performance are specific fuel consumption, turbine inlet temperature, thrust, and thrust to weight ratio.

3. The time during which the engine was developed. Time of development is important in that it is another measure of technology and performance. Later engines are more technologically advanced and have greater performance statistics which tend to increase O&S costs considerably more than their older counterparts. Conversely, increased technology might improve efficiency and reliability, thus decreasing costs. A variable indicative of time is number of fiscal year quarters from October 1942 to the engine Model Qualification Test (MQT) date. October 1942 was selected because it was the date when the first US turbojet-

powered aircraft flew (26:14). Another time variable is the number of fiscal year quarters from the MQT date to the fourth quarter of the fiscal year applicable to the cost data collected, e.g., MQT date to fourth quarter 1979, 1980, 1981, 1982, or 1983. A third measure of time is the average age of the aircraft fleet powered by the respective engines under study.

4. The amount of modification occurring to the engine. Continuous modification of jet engines would have a cost impact due to the procurement of modification and time compliance technical order kits. Additional labor cost from installing the modifications would also be incurred. Conversely, with class IV modifications to improve the maintainability, safety, and reliability of the engine, the maintainability of the engine should be expanded so that repairs and overhauls are less frequent. The number of class IV modification kits currently in progress during fiscal years 1979 through 1983 was selected as a variable indicative of the modification activity.

5. The frequency of overhaul maintenance. Increases in the mean time between overhaul would certainly decrease the depot maintenance contribution to O&S engine costs. As shown in the appendices, depot maintenance represents a sizeable contribution to the O&S cost of jet engines. Indicators of overhaul activity are the number of engines overhauled per year (production count) and the number of

engines removed for overhaul per year (both scheduled and unscheduled removals). The difference between the two indicators is an engine may be removed for overhaul in one period, but the actual overhaul may not occur until a later period. A third indicator of overhaul frequency is maintenance manhours. The more frequent and complex the overhaul, the more maintenance manhours are involved.

6. The amount of usage sustained by the engine. The more wear on the engine, the more frequently it reaches the maximum time between overhaul. The indicator selected for engine usage was engine flying hours per year.

The following Table IX summarizes the explanatory physical and performance variables examined for inclusion in the cost estimating relationship model. Values for each of the variables can be found in Appendix O.

TABLE IX

EXPLANATORY VARIABLES

Function	Variables
Size	Weight (WT)
Technology/ Performance	Specific Fuel Consumption (SFC)
	Turbine Inlet Temperature (TIT)
	Thrust (THRUST)
	Thrust to Weight Ratio (THWT)
Time	FY quarters from October 1942 to MQT date (MQT)
	FY quarters from MQT date to 4th qtr of the FY applicable to the cost data collected (ENGAGE)
	Average Age of Aircraft Fleet powered by the engine (AGE)
Modification Activity	Number of mod kits in progress per FY (MODS)
Overhaul Frequency	Production Count (PROD)
	Overhaul Removals (OHREM)
	Maintenance Man Hours (MMHRS)
Usage	Engine Flying Hours per Year (EFHRS)

Selection of the Dependent Variable

When costs were extracted in Chapter III, some erratic behavior was noted in the replenishment spares and modification kit costs. For some engines, costs were noted as missing or as not being incurred. Conversations with the Office of Primary Responsibility for those costs indicated that the data could be missing for several reasons. One would be the lack of historical documentation in which to extact the data. A second, would be the lack of historical memory, i.e., the turn over in personnel. Having the documents but lacking the personnel to interpret it would result in missing data. The third cause for missing data would be computer systems error. In order to average the erratic behavior of these sustaining investment components, their five year total was derived and the average yearly value was substituted for the actual sustaining investment costs.

Averaging the data has two impacts. First, the intercept term captures the available sustaining investment costs. Second, and unavoidably, the cost of sustaining investment is not able to vary with changes in the independent variables. The independent variable used in the cost estimating relationship is called Adjusted Cost (ADJC) to infer that the sustaining investment inputs were averaged and are not actuals.

Selection of the Cost Estimating Relationship

Multilinear stepwise regression was employed to test the ability of the selected independent variables to explain cost. Selection of the "best" cost estimating relationship relied on the following three selection criteria.

First, a simple model is preferred to a more complex model if the sacrifice in explanatory power is small.

Second the cost estimating relationship should be logical. Although the real test of a model is its ability to predict, it is important to understand why the independent variables affect cost in a certain way. Understanding how the variables affect cost ensures that the model will be properly applied and the effects of changing circumstances and technology will be correctly anticipated.

Third, variables that are proxies of each other should not be used in the same cost estimating relationship. When variables are proxies of each other, they can substitute for each other in the equation without changing the explanatory value of the equation. In this situation, the proxy variables are said to be multi-collinear. There are two reasons why multi-collinear variables in the same equation are to be avoided.

1. Even though the coefficient estimates remain unbiased, the variance of the coefficient estimates may increase dramatically. This effect makes it very difficult to reject the null hypothesis that a particular regression coefficient has a value of zero.

2. Inclusion of both proxy variables will make the equation more complex than necessary. Since one proxy variable can replace the second proxy variable, omitting one of the pair will not significantly reduce the explanatory power.

While there is no precise means of identifying multi-collinear relationships, a "rule of thumb" often applied in order to avoid multi-collinearity is to omit a variable if its correlation with another independent variable is greater than its correlation with the dependent variable (32). This rule was applied in formulating the cost estimating relationship of this thesis.

Chapter Summary

This chapter analyzed both the dependent and independent variables which are candidates for inclusion in a multivariable linear regression cost estimating relationship. The results of the thesis research are presented in Chapter V.

Chapter V. Analysis

Chapter Overview

This chapter will achieve the final thesis research objective by determining the best multivariable linear regression cost estimating relationship model and by analyzing the statistical properties of the model.

Model Selection

With the aid of stepwise regression analysis, the dependent variable ADJC (adjusted cost) was regressed against combinations of all twelve independent predictor variables. The stepwise algorithm used begins by finding the one-variable model that produces the highest R2. Variables are added one by one to the model. After a variable is added, all the variables already in the model are examined and any variable that does not produce a F-statistic at the .10 level of significance is deleted. Only after the examination and possible deletion of insignificant variables can another variable be added to the model. The process ends when no variable has a significant F-statistic or when the variable added to the model is the one just deleted from it (36:391). Following the selection criteria established in Chapter IV (logic and high R2) only one model stood out as both logical and having a high level of explanatory power. The equation for the model is

$$ADJC = -415350 + 184.307\ TIT + 93565.729\ SFC + 18.962133\ WT + .049260\ EFHRS$$

In the rejection process, it was noted that all the higher explanatory models contained the same four basic physical and performance characteristics in combination with other variables. Those four variables were TIT (turbine inlet temperature), SFC (specific fuel consumption), WT (weight), and EFHRS (engine annual flying hours). Although other models sometimes had higher adjusted R2, they contained variables which appeared to be highly collinear with TIT, SFC, WT, and EFHRS. Since their contribution to the explanatory power of the equation was marginal (typically they only raised the adjusted R2 by around .04), it was decided to omit those variables. Among the collinear variables were the combinations in Table X. Each of these combinations had a correlation coefficient of .8 or greater. Variables with an asterisk are those included in the cost estimating relationship.

TABLE X

COLLINEAR COEFFICIENTS

	TIT	WT	THRUST	THWT	PROD	ENGAGE	MQT	OHRMEM
TIT*	-	-	-	.843	-	-.926	.942	-
WT*		-	.909	-	-	-	-	-
THRUST			-	-	-	-	-	-
THWT				-	-	-.844	.858	-
PROD					-	-	-	.962
ENGAGE						-	-.985	-
MQT							-	-
OHREM								-

When two variables had a higher correlation with each other than what they did with the dependent variable in separate correlations, only one variable was kept for inclusion in the cost estimating relationship. The variable selected for inclusion was the one which contributed to the highest adjusted R2.

Model Evaluation

The same evaluation techniques used by the Rand researchers (6:17-22) were applied to the selected model. A full set of statistics were obtained for the model and are depicted in Table XI.

TABLE XI

SELECTED MODEL STATISTICS

Dependent Variable: ADJC

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	538599490734	134649872684	80.596	0.0001
Error	45	75180486883	1670677486		
C Total	49	613779977618			

Root MSE	40873.922	R-Square	0.8775
Dep Mean	138746	Adj R-Sq	0.8666
C. V.	29.45946		

Variable	DF	Estimate	Error	Parameter=0	Prob>T
Intercep	1	-415350	38282.157	-10.850	0.0001
TIT	1	184.307	17.615742	10.463	0.0001
SFC	1	93565.729	7876.178	11.880	0.0001
WT	1	18.962133	3.869400	4.901	0.0001
EFHRS	1	0.049260	0.010832	4.548	0.0001

This model meets all the model criteria addressed in Chapter IV. First, the model is logically related to O&S costs. The independent variables TIT SFC WT and EFHRS all contribute to the O&S cost of jet engines in that they are functions of size, technology, performance, and usage. Second, the variables are all known with a fair degree of accuracy. Third, the values for the physical and performance variables are available in the Engine Handbook and the EFHRS values have been collected from the Weapons System Cost Retrieval System (WSCRS) during the cost data collection process. Fourth, the model also meets the criteria for cost estimating relationship selection in that all the coefficients on the independent variables are positive as would be expected from functions of weight, technology, performance, and usage. The variables have been limited to four. This allows for the employment of simplicity in the model while still retaining high explanatory powers indicative by the 0.8775 R2.

Usefulness of the Selected Equation

The cost estimating relationship equation selected is based on three physical and performance characteristics (TIT, SFC, and WT) and one usage factor (EFHRS). These factors allow for both design and usage to be predictors for annual partial O&S costs on jet engines currently in the US Air Force active Inventory.

Use of a cost estimating relationship allows for the analysis of the impact on cost as one of the explanatory variables change, e.g., if the design parameter TIT is increased, then holding all other variables constant, the effect of TIT on ADJC can be evaluated.

A cost estimating relationship allows for the separation of fixed costs from variable costs. The fixed portion can be found in the intercept term. The variable portion can be found in the coefficients preceding the explanatory variables.

With a cost estimating relationship, variable cost factors can be obtained for use in comparative cost analyses of present and proposed weapon systems; in cost tradeoff studies to determine impact of design alternatives for new engines; in reports to Congress on the costs of operating engines; and in estimating budget requirements.

Examples of how to use the cost estimating relationship are

- Determine the annual O&S cost impact of flying an additional 1000 engine flying hours with all other variables remaining constant. To do so requires the 1000 engine flying hours to be multiplied by the coefficient 0.049260. This produces 49.260 in thousands of FY85 dollars, or $49,260.00 in O&S cost for 1000 engine flying hours.

- Determine the O&S cost impact of an engine that has an annual usage of 36,000 engine flying hours, has a turbine inlet temperature of 1970 degrees Farenheit, has a maximum specific fuel consumption of 2.5, and weighs 4062 pounds. With the given information, the equation would look like this:

$$ADJC = -415350 + 184.307\ (1970) + 93565.729\ (2.5) + 18.962133\ (4062) + .049260\ (36{,}000)$$

The result would be ADJC = $260,447 in thousands of FY85 dollars.

- For the above example, determine the annual partial O&S costs per engine flying hour. To do so requires the $260,447 in thousands of FY85 dollars to be divided by 36,000 engine flying hours. The result is $7,235 in FY85 dollars.

Chapter Summary

This chapter identified the best multivariable linear regression cost estimating relationship model. The model's statistical properties were analyzed and the model was found to be both logically and statistically sound.

Chapter Six will complete the thesis efforts by providing conclusions and suggestions for future research.

Chapter VI. Conclusions and Suggestions for Future Research

Limitations of the Results

The regression equation is based on a data set which considers ten HQ AFLC maintained engines at the type/model level of indenture. For each engine there are five years of data. This provides the data base with fifty data points. Consolidating the data pertinent to ten engines into one data base consolidates all their experience together e.g., what drives cost for the TF34 engine also drives cost in the TF41 engine. This consolidation helps to compensate for the small sample sizes of each engine (five points) and it helps to reduce the variances of the regression coefficient estimates. This consolidation process assumes that each engine will have the same fixed cost, i.e., the intercept term. While the assumption may be valid, it has not been tested in this thesis effort. Additional annual cost data collection by type/model/series level would increase the data points for each engine. With a sufficient number of data points for each engine, a separate cost estimating relationship for each engine might be developed. The results of ten separate cost estimating relationship versus one consolidated one is that fixed costs would be more reflective of the individual engine and variable costs would be reflective of changes in the respective engines' programs. Attempts to study this issue were thwarted by the small sample size and lack of variability in the data sets associated with individual engines. Future research based upon experience over a longer period of time and which includes more engines may be able to address this particular issue.

The cost data upon which the regression model is based are non-homogeneous. Some of the costs are obligations (reflective of purchases to be consumed at a later period) and others are expenditures (reflective of when the resources are consumed). The use of obligation data makes it more difficult to study the relationship of changes in the independent variables to changes in cost. The same type of limitation was imposed by the necessity of averaging sustaining investment material cost data. The cost estimating relationship estimates obtained could be improved by the removal of these limitations.

Another limitation is that the data set included Foreign Military Sales in the replenishment spares contribution to cost. Inclusion of spares purchased for Foreign Military Sales inflates the replenishment spares contribution to the O&S costs of US Air Force engines and may have marginally reduced the explanatory power of the cost estimating relationship.

The estimate derived from the use of this thesis model is not a total O&S estimate. The cost estimating structure upon which this thesis is structured represents only partial O&S costs. Personnel training, retirement, computer software, and jet fuel were not addressed in the cost element structure and were omitted from this thesis effort. Due to lack of data, the base maintenance contribution to cost was also deleted. In addition, the second destination transportation contribution is only partial in that it does not capture the cost effect of shipping spares among the depots and installations.

As with all regressions, the equation was derived from a limited number of sample members. All of the members are engines under HQ AFLC maintenance responsibility. All of the members are older engines and have been in the active Air Force Inventory for some time. Use of this cost estimating relationship model for estimation of newer, non-HQ AFLC maintained engine costs warrants caution. In addition, this model is not recommended for predictive purposes for those engines whose physical and performance characteristics exceed the values of the sample engines.

Suggestions For Future Research

Chapter II searched for data bases from which to develop a predictive jet engine O&S cost model. Limitations and constraints of each data base were identified. A recommended thesis effort would be to study each data base and evaluate how the data collection and reporting process could be enhanced so as to allow the data bases to be more conducive to jet engine cost prediction purposes.

A systems analysis of the transportation process at the Air Logistic Centers would be beneficial. The purpose of the analysis would be to trace the shipping documentation of engines and engine spares to determine if shipping costs could be collected at the jet engine type/model/series level of indenture.

Closing Remarks

This thesis has taken the original HQ AFAFC/CWM efforts several steps further. First, it has identified and evaluated all pertinent data bases from which jet engine O&S costs could be developed. Second, a predictive model was derived from the available jet engine O&S cost data. From the model the following benefits can be gained:

- Partial O&S costs can be predicted.
- The effects of variable costs can be evaluated.
- Cost factors can be derived.

Future improvements will require more homogeneous data at the type/model/series level of indenture. Until accurate data at that level can be compiled, a predictive means for determining jet engine costs will have to be based on a composite model.

Appendix A: Cost Element Definitions

Depot Level Cost Elements

Depot Maintenance: That maintenance which is the responsibility of and performed by designated maintenance activities, to augment stocks of servicable material, and to support Organizational Maintenance and Intermediate Maintenance activities by the use of more extensive shop facilities, equipment and personnel of higher technical skill than are available at the lower levels of maintenance. Its phases normally consist of inspection, test, repair, modification, alterations, modernization, conversion, overhaul, reclamation or rebuilding parts, assemblies, subassemblies, components, equipment, end items, and weapon systems: the manufacture of critical, nonavailable parts: and providing technical assistance to intermediate maintenance organizations, using and other activities. Depot maintenance is normally done in fixed shops or by depot field teams (13:82).

Direct Labor: Production-type "hands-on" labor performed by a Resource Control Center of a maintenance production branch or laboratory. Direct labor is defined as that labor which (1) increases the value or utility of a product by altering the composition, condition, conformation, or construction of the product or which provides a service directly to the customer rather than in support of other direct labor in the Directorate of Maintenance; (2) can be accurately, consistently, and economically identified to a product, group of products, or customer; (3) is supported by official work requests and authorized by prescribed work authorization documents (WAD) indicating the specific nature of the work to be done; and (4) is applied to the product or group of products of a customer outside the Directorate of Maintenance (13:83).

Modification Installation Labor: That direct labor expended in the installation of modification kits.

Direct Material: Expense material that enters directly into or becomes a part of the functional characteristic of the product and can be related to specific end items or readily measured and charged to specific job or end products (13:83).

Government Furnished Material: Any item of government property provided to a government contractor for incorporation in the end articles to be produced under the terms of the contract (13:83).

Operations Overhead: Is all indirect labor, indirect material, and services that can be reasonably allocated or economically identified to a Resource Center. Operations overhead costs include the maintenance functions of Production Division Administration, Production Branches above Resource Center level, Operations Branch, Planning and Engineering Branch, Scheduling Branch, Inspection Branch, and the Quality Assurance Branch (13:84).

Other Direct Cost: This is the cost of per diem and travel expenses incurred in support of mission TDY. It also includes the cost of contract services performed in support of organic workloads. This includes contract support services only; it doesn't include contract depot level maintenance costs (13:84)

Base Level Cost Elements

Base Maintenance Support: Organizational and intermediate maintenance performed below depot level. It includes contractors performing at this level but excludes depot level maintenance performed at base level (13:82)

Direct Labor: Same definition as Depot Maintenance Direct Labor, but, as it pertains to the base level environment.

Direct Material: Same definition as Depot Maintenance Direct Material, but, as it pertains to the base level environment.

Indirect Labor, Material, and Non-Maintenance: Include base level operations overhead categories of cost.

Other Cost Elements

Contractor Maintenance: Any maintenance performed under contract by commercial organizations (13:82).

Sustaining Investment: Includes Class IV Modification Kit and Replenishment Spares purchases.

Class IV Modification Kits: Parts installed to correct an equipment deficiency or installtion deficiency that affects maintainability, reliability, or inflight safety (13:82).

Replenishment Spares: Include those repairable components, assemblies, or subassemblies required to resupply initial stockage or increase stockage for reasons other than support of newly fielded end items during peacetime (40). The type of spares addressed by this thesis are called Peacetime Operating Stock (POS).

Second Destination Transportation: The cost of freight, cartage, handling charges, and the like of items shipped from the first station or depot to the second station or depot (37:613). This thesis addresses costs for transfer of whole engines only. Repairable components are not included in the estimates.

Appendix B: Functional Definitions

TURBOJET: The turbojet is the basic engine of the jet age. Air is drawn in through the front intake. The compressor squeezes the air to many times normal atmospheric pressure and forces it into the combustion section. Here, fuel is sprayed into the compressed air, is ignited and burned continuously like a blowtorch. The burning gases expand rapidly rearward and pass through the turbine. The turbine extracts energy from the expanding gases to drive the compressor, which packs in more air. After leaving the turbine, the hot gases blast their way out the rear of the engine, giving the aircraft its forward push. . .action, reaction (21:28).

TURBOPROP: A turboprop engine uses thrust to turn a propeller. As in a turbojet, hot gases rushing through the engine rotate a turbine wheel that drives the compressor. The gases then pass through another turbine, called a power turbine. This power turbine is coupled to the shaft which drives the propeller through gear connections (21:29).

TURBOFAN: A turbofan engine is basically a turbojet to which a fan has been added. Turbofans can be placed either at the front or the rear of the engine. In the case of a front fan, the fan is driven by a second turbine, located behind the primary turbine that drives the main compressor. The fan causes more air to flow around the engine than through it. This produces greater thrust and reduces specific fuel consumption at subsonic and certain supersonic speeds (21:30).

Appendix C: Historical Depot Maintenance Cost Per Engine at the Type/Model Level FY85 (000) Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	47939	41731	34170	40025	39606
TF34	4009	8740	18104	11375	21011
J57	84905	84453	87626	80216	51960
TF33	29457	31385	40457	47056	58205
TF39	22832	29690	36300	61059	99249
T56	34825	34812	39457	47107	63976
J79	74249	72920	63496	101757	145184
F100	42953	61439	80580	93421	128263
TF30	62705	62647	80896	95236	75913
J33	1504	3440	2944	3383	2248

Content of the above depot maintenance costs include direct labor (military/civilian/other); direct material; government furnished expense material; government furnished services; operations overhead; other direct materials, labor, and non-maintenance; and contractor and interservice.

Appendix D: Depot Maintenance Cost Per Engine Flying Hour at the Type/Model Level FY85 Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	500	450	400	470	460
TF34	20	30	50	20	40
J57	50	50	50	50	60
TF33	10	10	20	20	30
TF39	110	140	170	280	450
T56	20	20	20	30	40
J79	90	100	80	140	200
F100	220	260	260	230	270
TF30	330	340	420	490	390
J33	20	60	50	60	40

Content of the above depot maintenance cost factors include direct labor (military/civilian/other); direct material; government furnished expense material; government furnished services; operations overhead; other direct materials, labor, and non-maintenance; and contractor and interservice.

Appendix E: Historical Engine Flying Hours Per Engine at the Type/Model Level

T/M	FY79	FY80	FY81	FY82	FY83
TF41	94101	91423	83759	83770	85202
TF34	153820	237024	328360	427244	454328
J57	1604084	1618244	1640096	1577203	858284
TF33	1635844	1634376	1701604	1744364	1813400
TF39	194628	204532	208640	212080	217400
T56	1244368	1423236	1457532	1508792	1494568
J79	788302	720826	706244	686126	699506
F100	186792	232931	299732	394713	465715
TF30	187180	183433	190094	190862	192892
J33	56709	54165	53532	52812	51895

The above engine flying hours were extracted from the Weapon System Cost Retrieval System data base.

Appendix F: Historical POS Replenishment Spares Cost Per Engine at the Type/Model Level FY85 (000) Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	11774	5674	8050	25193	31473
TF34	17745	5248	51572	43445	97981
J57	134163	29362	28805	53856	44774
TF33	0	0	0	0	173040
TF39	40962	141276	110566	412853	75297
T56	0	0	13082	34704	0
J79	17579	36170	57987	74293	78741
F100	316086	162553	220629	360026	489074
TF30	80265	91064	133585	83548	297862
J33	3151	2695	1887	2699	0

The above POS replenishment spares costs were extracted form a HQ AFLC/MMMIR locally used data base. The costs do include Foreign Military Sales contributions. Zero values are indicative of lack of source data or lack of purchases for that year.

Appendix G: Historical Class IV Modification Kit

Cost Per Engine at the Type/Model Level

FY85 (000) Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	3945	2428	5574	26549	32544
TF34	0	0	0	320	0
J57	0	0	0	0	0
TF33	0	0	0	568	408
TF39	320	0	1586	632	317
T56	58	36	0	0	0
J79	0	0	0	17010	24821
F100	0	0	0	0	14607
TF30	2790	2802	2908	50773	43216
J33	0	0	0	0	0

The above class IV modification kit costs were provided by ALC funds managers. Zero entries indicate no purchases made that year.

Appendix H: Historical Sustaining Investment Cost Per Engine at the Type/Model Level FY85 (000) Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	15719	8102	13624	51742	64017
TF34	17745	5248	51572	43765	97981
J57	134163	29362	28805	53856	44774
TF33	0	0	0	568	173448
TF39	41282	141276	112152	413485	75614
T56	58	36	13082	34704	0
J79	17579	36170	57987	91303	103562
F100	316086	162553	220629	360026	503681
TF30	83055	93866	136493	134321	341078
J33	3151	2695	1887	2699	0

Content of the above costs include Peacetime Operating Stock (POS) replenishment spares and class IV modification kit costs. Foreign Military Sales contributions are also included in the replenishment spares values. Some historical spares data is missing.

Appendix I: Sustaining Investment Cost Per Engine Flying Hour at the Type/Model Level FY85 Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	160	80	160	610	750
TF34	110	20	150	100	210
J57	80	10	10	30	50
TF33	0	0	0	0	90
TF39	210	690	530	1940	340
T56	0	0	9	20	0
J79	20	50	80	130	140
F100	1690	690	730	910	1080
TF30	440	510	710	700	1760
J33	50	40	30	50	0

Content of the above factors include Peacetime Operating Stock (POS) replenishment spares and class IV modification kit costs. Foreign Military Sales contributions are also included in the replenishment spares values. Some historical spares data is missing.

Appendix J: Partial Second Destination Transportation Cost Per Engine at the Type/Model Level FY85 (000) Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	260	205	178	140	99
TF34	3	8	6	24	30
J57	757	752	778	714	373
TF33	143	141	175	276	226
TF39	102	89	164	300	442
T56	112	146	269	297	342
J79	757	760	733	816	741
F100	235	258	459	498	589
TF30	409	343	373	430	436
J33	0	2	5	4	4

The above partial SDT costs include estimates for shipment of whole jet engines and estimates for shipping the modular units of the F100 and T56 engines. Repairable items shipment costs are not included.

Appendix K: Partial Second Destination Transportation Cost Per Engine Flying Hour at the Type/Model Level

FY85 Dollars

T/M	FY79	FY80	FY81	FY82	FY83
TF41	3	2	2	2	1
TF34	0	0	0	0	0
J57	0	0	0	0	0
TF33	0	0	0	0	0
TF39	0	0	0	1	2
T56	0	0	0	0	0
J79	1	1	1	1	1
F100	1	1	2	1	1
TF30	2	2	2	2	2
J33	0	0	0	0	0

The above partial SDT cost factors include estimates for shipment of whole jet engines and estimates for shipping the modular units of the F100 and T56 engines. Repairable items shipment costs are not included. In the event the computed cost per engine flying hour was less than one dollar, the amount entered was zero.

Appendix L: O&S Cost Per Engine Flying Hour

For Engines Maintained by HQ AFLC

Type/Model Level

FY85 (000) Dollar

T/M	FY79	FY80	FY81	FY82	FY83
TF41	670	540	570	1090	1210
TF34	140	50	210	120	260
J57	130	70	70	80	110
TF33	10	10	20	20	120
TF39	320	830	710	2230	800
T56	20	20	30	50	40
J79	110	150	170	280	350
F100	1920	960	1000	1150	1350
TF30	780	850	1140	1200	2160
J33	80	110	90	110	40

The above O&S cost per engine flying hour for engines under HQ AFLC responsibility sum the costs for depot level maintenance, POS replenishment spares, class IV modification kit costs, and partial second destination on whole engines.

Appendix M: O&S Cost Per Engine Flying Hour for Engines Under Systems Command Maintenance Responsibility at the Type/Model Level FY85 Dollars

Engine	Estimate
F100-110	$240 - $315 / EFHR
F100-220	$240 - $315 / EFHR
F108	$52.50 / EFHR
F101-100	$280 / EFHR
F101-102	$280 / EFHR

The above O&S cost per engine flying hour for engines under HQ Systems Command maintenance responsibility are derived from the BOSC model. Content of the estimates include depot level maintenance, base maintenance, and replenishment spares.

Appendix N: O&S Cost Per Engine Flying Hour for Engines Under Contract Logistics Support at the Type/Model Level

FY85 Dollars

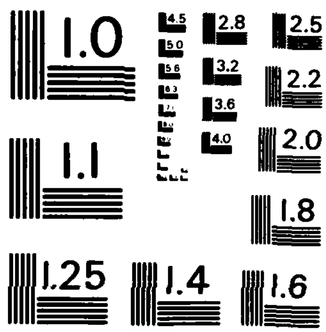
Engine	FY81	FY82	FY83	FY84
F103-100	53	56	59	58

The above O&S cost per engine flying hour were derived from contractor proposals. Content of the estimates include engine overhaul, intermediate repair, and replenishment spares.

AD-A161 683 JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. B H COX 2/2

UNCLASSIFIED SEP 85 AFIT/GSM/LSY/85S-8 F/G 14/1 NL

END
FILMED
DTIC


1.0
4.5
2.8
2.5
5.0
5.6
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Appendix O: Physical and Performance Characteristics

Engine	WT Lbs	SFC	TIT Fo	THRUST Lbs	MQT Qtrs
TF30	4062	2.5	1970	18500	98
TF34	1421	.37	2234	9065	130
TF41	3175	.647	2157	14500	108
TF33	3905	.52	1600	16500	72
J79	3685	1.945	1775	17000	82
J57	3870	.775	1600	13750	55
T56	1833	.528	1780	3775	62
TF39	7186	.315	2350	40805	110
F100	3021	2.17	2565	23840	126
J33	1820	1.14	1265	4900	21

Engine	FY	ENGAGE	AGE	MODS	PROD	OHREM	MMHRS
TF30	79	52	8.8	10	476	341	1096480
	80	56	9.3	10	438	343	1170580
	81	60	10.3	10	441	372	1247660
	82	64	11.3	8	459	434	1348908
	83	68	12.3	8	483	422	-
TF34	79	20	1.3	0	6	14	16919
	80	24	1.7	0	21	17	4593
	81	28	2.0	0	14	31	13
	82	32	2.3	1	50	55	3418
	83	36	2.9	1	64	55	-
TF41	79	41	6.9	5	297	220	436754
	80	45	8.0	5	257	171	396621
	81	49	8.6	6	207	149	344952
	82	53	11.2	12	147	81	314138
	83	57	12.2	16	115	76	-
TF33	79	77	18.0	12	126	96	1279323
	80	81	19.0	7	136	119	1381084
	81	85	20.4	8	156	152	1311670
	82	89	21.0	11	223	170	1213916
	83	93	22.0	11	189	206	-
J79	79	68	10.4	3	619	656	1407074
	80	72	11.3	2	682	617	1478894
	81	76	13.2	2	608	549	1281676
	82	80	12.7	2	612	559	919409
	83	84	13.5	1	576	490	-
J57	79	94	19.6	16	546	372	1286529
	80	98	20.8	13	595	320	1391015
	81	102	21.8	12	570	359	1327382
	82	106	22.7	12	472	339	1216261
	83	110	23.1	12	256	312	-
T56	79	88	11.8	8	257	299	407800
	80	92	12.8	8	368	257	478071
	81	96	16.7	1	433	341	543513
	82	100	14.8	2	432	398	467726
	83	104	15.8	5	517	445	-
TF39	79	40	7.8	20	28	39	421593
	80	44	8.8	23	27	35	581122
	81	48	9.8	7	46	53	559761
	82	52	10.8	8	76	97	419718
	83	56	11.8	8	116	84	-

Engine	FY	ENGAGE	AGE	MODS	PROD	OHREM	MMHRS
F100	79	24	2.0	0	94	99	604092
	80	28	2.5	0	120	104	699236
	81	32	3.1	0	162	145	1466817
	82	36	3.7	0	130	122	1143322
	83	40	4.5	0	156	182	-
J33	79	129	21.3	0	0	10	0
	80	133	22.3	0	0	3	0
	81	137	24.0	0	0	9	0
	82	141	24.3	0	0	7	0
	83	145	25.4	0	0	7	-

Data Sources:

WT, SFC, TIT, THRUST, MQT, ENGAGE extracted from or derived from Engine Handbook (13).

AGE extracted from Calendar Age of Aircraft Reports (11).

MODS extracted from Modification Program Progress Reports (24).

PROD extracted from HQ AFLC Depot Maintenance Annual Reports (2).

OHREM extracted from ALC Summary Engine Removals Reports (34).

MMHRS extracted from Organizational and Intermediate Maintenance, USAF Consolidated Cost Reports (1).

Bibliography

1. Accounting and Finance Center. Organizational and Intermediate Maintenance, USAF Consolidated Cost Report. RCS: HAF-ACXF (Q) 7403. Lowry AFB CO: HQ AFAFC, 1979 through 1983.

2. Air Force Logistics Command. Depot Maintenance Annual Report. Wright-Patterson AFB OH: HQ AFLC, 1979 through 1983.

3. Air Force Logistics Command. Cost Analysis: AFLC Cost and Planning Factors. AFLCP 173-10 Wright-Patterson AFB: HQ AFLC, 1979 through 1983.

4. Air Force Logistics Command. Engine Production Counts. RCS LOG-MA (Q) 7312. Wright-Patterson AFB: HQ AFLC, 1979 through 1983.

5. Banz, Edward, Funds Manager, Resource Management Division, Modification Branch, Policy and Programs Section. Telephone interview. Kelly Air Logistics Center, San Antonio TX, 5 March 1984 and 5 March 1985.

6. Birkler, J. L., J. B. Barfinkle, and K. E. Marks. Development and Production Cost Estimating Relationships for Aircraft Turbine Engines. October 1982. Contract F49620-82-C-0018. Rand Corporation, Santa Monica CA, October 1982 (AD-A123 753).

7. Cost and Economic Analysis Division, Comptroller Support Directorate, HQ AFAFC. Memorandum for Record. Lowry AFB CO, 15 March 1984.

8. Cost and Economic Analysis Division, Comptroller Support Directorate, HQ AFAFC. Report of Visit. Lowry AFB CO, 17 February 1984.

9. Cost and Managment Analysis Division, Headquarters Air Force Logistics Command. Depot Maintenance Weapon System Cost Data. RCS: HAF-ACM (A&AR) 8202. Wright-Patterson AFB: HQ AFLC, 2 March 1984.

10. Dahm, Cpt Robert and Charlie Clark, Program Analysts, Program Control Division, Directorate of KC-10 Deputy for Airlift and Trainer Systems, Aeronautical Systems Division. Personal and telephone interviews 24 February 1984 through 6 June 1985.

11. Department of the Air Force. Calendar Age Of Aircraft. Washington: HQ USAF, 1979 through 1983.

12. Department of the Air Force. Cost Analysis: US Air Force Cost and Planning Factors. AFR 173-13. Washington: HQ USAF, 1 February 1984.

13. Department of the Air Force. Cost Analysis: Weapon System Cost Retrieval System (WSCRS). AFLCM 173-264. Washington: HQ USAF, 3 October 1983.

14. Deputy Chief of Staff for Logistics Operations. Engine Handbook. Wright-Patterson AFB: HQ AFLC, October 1982.

15. Drake, Maj Mike. "Component Support Cost System (CSCS)." Report to Cost and Economic Analysis Division, Comptroller Support Directorate. HQ AFAFC, Lowry AFB CO, 14 February 1984.

16. Fisher, Gene H. Cost Considerations in Systems Analysis. New York: American Elsevier Publication Company Incorporated, 1971.

17. General Accounting Office. The Air Force Can Improve Its Maintenance Information Systems Report to the Chairman Committee On Government Operations House of Representatives. Report number GAO/GSD-83-20. Washington: General Accounting Office, 25 January 1983.

18. Hall, Brig Gen David, M., Deputy Chief of Staff Comptroller. Letter. HQ AFLC, Wright-Patterson AFB OH, 22 April 1983.

19. Howenstein, Cpt M.J., Program Analyst, Office of VAMOSC, HQ AFLC. Personal interview. Wright-Patterson AFB OH, 3 December 1984.

20. Hurley, Steve, Requirements Analyst, Material Maintenance Division. Telephone interview. San Antonio Air Logistics Center TX, 16 Apr 1985.

21. Jet Propulsion. Product Brochure. General Electric Corporation, Cincinnati, OH, undated.

22. Kidwell, Mike, Funds Manager, Propulsion Management Division, Plans and Management Section, Engine Management Branch. Letter. Tinker Air Logistics Center, Oklahoma City OK, 4 April 1984.

23. Larson, Msgt, Maintenance Chief of Data Automation. Telephone interview. Lowry AFB CO, 26 January 1984.

24. Material Management Division, HQ AFLC. Modification Program Progress Report. Wright-Patterson AFB OH, Fiscal Years 1979 through 1983.

25. Material Management for Investment Spares Branch, Director of Material Management. Requirements/Funding History. Wright-Patterson AFB: HQ AFLC, 8 February 1985.

26. Nelson, J. R. Life-Cycle Cost Analysis of Aircraft Turbine Engines: Interim Report. Contract F49620-77-C-0023, Rand Corporation, Santa Monica CA, November 1977 (AD-A050 349).

27. Office of the Secretary of Defense, Cost Analysis Improvement Group. Aircraft Operating and Support Cost Development Guide. Washington: Office, Secretary of Defense, 15 April 1980.

28. Owen, Lt Col Don, Cost Analyst, Cost and Management Analysis Directorate, Cost Analysis Division. Personal interview. HQ USAF Pentagon, 5 February through 8 February 1984.

29. Owen, Lt Col Don, Cost Analyst, HQ USAF, Cost and Economic Analysis Division and Abraham, Lt Col Warren, Chief, Cost and Management Analysis Branch, Air Force Accounting and Finance Center. Staff Visit to HQ AFLC, Cost and Management Analysis Division, Wright-Patterson AFB OH, 21 February 1985.

30. Owens, Robert C., Chief, Cost Analysis Division, Directorate of Cost and Management Analysis. Letter. HQ USAF, 21 January 1983.

31. Penry, Roger, Cost Analyst, Requirements and Planning Office, Propulsion Systems Division, Air Force Aeronautical Logistics Center. Personal interviews. Wright-Patterson AFB OH, 2 November 1984 through 31 July 1985.

32. Pindyck, Robert S. and Daniel L. Rubinfeld. Econometric Models and Economic Forecasts. New York: McGraw-Hill Book Company, 1976.

33. Price, Eilanna, Cost Analyst, Requirements and Planning Office, Propulsion Systems Division, Air Force Aeronautical Logistics Center. Personal interviews. Wright-Patterson AFB OH, 2 November 1984 through 31 July 1985.

34. Propulsion Management Division, Engine Management Branch. Summary Engine Removals. Oklahoma City and San Antonio Air Logistics Centers, Fiscal Years 1979-1983.

35. Ramsey, Chuck, Budget Analyst. Director Programs/Resources, Budget Requirements Division, HQ AFLC. Telephone Interview. Wright-Patterson AFB OH, 4 March 1985.

36. SAS Institute Incorporated. SAS User's Guide. Cary, North Carolina: SAS Institute Incorporated, 1979.

37. School of Systems and Logistics. Compendium of Authenticated Systems and Logistics Terms, Definitions and Acronyms. AU-AFIT-LS-3-81. Wright-Patterson AFB: Air Force Institute of Technology, 1981.

38. Steinlage, Roger, Cost Analyst, Cost Analysis Division, HQ AFLC. Personal interview. Wright-Patterson AFB OH, 30 November 1984 through 6 June 1985.

39. Traffic Management Branch, Oklahoma City Air Logistics Center. Transportation Plan 71-1: Jet Aircraft Engines. Tinker AFB OK, April 1978.

40. Walker, Steve, Engine Management Specialist, Financial Management for Investment Spares Branch, Director of Material Management. Personal interviews. HQ AFLC, Wright-Patterson AFB OH, 8 February through 31 July 1985.

VITA

Brenda H. Cox was born on 22 July 1952 in Wilmington, North Carolina. She graduated from North Duplin High School in Calypso, North Carolina and attended North Carolina State University from which she received a Bachelor of Science in Poultry Science in May 1974. Her professional training came from the Management Analysis Division of the XVIII Airborn Corps and Fort Bragg at Fort Bragg North Carolina. After three years of internship at Fort Bragg, she accepted the position of Chief, Cost and Management Analysis at Pope Air Force Base North Carolina. During this period she attended Comptroller Staff Officer School and Professional Military Comptroller School. In 1983 she accepted a career broadening position with the Cost and Economic Analysis Division, Comptroller Support Directorate, Headquarters, Air Force Accounting and Finance Center, Lowry Air Force Base. She performed special studies for the Cost and Economic Analysis Division until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1984.

Permanent address: P. O. Box 1159
Carolina Beach, NC 28428

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A161 683

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFIT/GSM/LSY/85S-8

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
School of Systems and Logistics

6b. OFFICE SYMBOL (If applicable)
AFIT/LSY

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State and ZIP Code)
Air Force Institute of Technology
Wright-Patterson AFB, Ohio 45433

7b. ADDRESS (City, State and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State and ZIP Code)

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.

11. TITLE (Include Security Classification)
See Box 19

12. PERSONAL AUTHOR(S)
Brenda H. Cox

13a. TYPE OF REPORT
MS Thesis

13b. TIME COVERED
FROM ______ TO ______

14. DATE OF REPORT (Yr., Mo., Day)
1985 September

15. PAGE COUNT
104

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.
14	01	
21	05	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Aircraft Engines, Jet Engines, Turbofan, Turbojet, Turboprop, Cost Analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: JET ENGINE OPERATING AND SUPPORT COST ESTIMATING RELATIONSHIP DEVELOPMENT

Thesis Chariman: H. Leroy Gill, PHD
Associate Professor of Economics

Approved for public release: IAW AFR 190-17.
Lynn E. Wolaver 11 Sept 85
LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
H. Leroy Gill, PHD

22b. TELEPHONE NUMBER (Include Area Code)
513-255-3355

22c. OFFICE SYMBOL
AFIT/LSY

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

This investigation derived a jet engine Cost Estimating Relationship (CER) model from multivariate linear regression techniques. Prior to the model's development, all known jet engine cost data bases were examined for applicability to the thesis effort. After identifying constraints and limitations in the data, stepwise regression techniques were employed to identify multivariable regression equations for analysis. The "best" equation was identified based on pre-established logic and statistical criteria. The equation selected had the following performance, physical, and usage variables: Turbine Inlet Temperature, Specific Fuel Consumption, Weight, and Annual Engine Flying Hours.

Results of the model development can be used in comparative cost analyses of present and proposed weapon systems; in cost trade-off studies to determine impact of design alternatives for new engines; in reports to Congress on the costs of operating engines; and in estimating budget requirements.